Nuclear Science

The LEGS Collaboration – X5

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The Laser Electron Gamma Source (LEGS) provides intense, polarized monochromatic γ-ray beams by Compton backscattering laser light from relativistic electrons circulating in the X-Ray storage ring of the National Synchrotron Light Source at Brookhaven National Laboratory. Such a beam has a high degree of polarization (typically ~90%) with very low background, and the energies of the photons are well determined by measuring the loss of energy of the struck electrons (±1%). Photon energies up to 470 MeV can be obtained with the new frequency-quadrupled laser and 2.8 GeV stored electrons.

The LEGS facility and collaboration continues to be in a time of transition. Facility upgrades are nearing completion, and the program of double-polarization measurements is scheduled to begin in 2001. Highlights of this year's progress are given below. An updated status of LEGS, including recent publications, is available on the web at http://www.legs.bnl.gov/.

The N→Δ Transition and Proton Polarizabilities

A group paper describing full details of high precision measurements of pion photoproduction and Compton scattering from the proton using linearly polarized photons at LEGS has been submitted for publication in Physical Review C. [1] The cross-sections are locked together with a small common systematic scale uncertainty of 2%, and the polarization asymmetry data are of the highest precision yet available. These data formed the basis for the first simultaneous multipole analysis of both Compton scattering and π-production. The use of the two new constraints from Compton scattering resulted in sizeable alterations to several multipoles and has provided a new high precision determination of the electric quadrupole component in the N→Δ transition (EMR).

This simultaneous multipole analysis also led to the first determination of the four proton *spin-polarizabilities*. The proton's lowest order scattering response is fixed by its static properties of mass, charge, magnetic moment and spin. The leading corrections to this *point* scattering arise from the dynamic rearrangement of constituent charges and spins within the proton, and are expressed in terms of *six polarizabilities.* Four of these quantities describe the dynamical reorientation of the constituent spins in response to the fields of a photon during scattering. In particular, the forward (γ_0) and backward (γ_p) spin polarizabilities measure the strength of that component of the transient dipole moment which tends to orient the nucleon spin along the photon beam direction. The extracted value of γ_p is -[27.23±2.27(*stat+sys*)+2.24/-2.10 (*model*), and is considerably different from other analyses. This has been instrumental in bringing the difference in the dipole polarizabilities extracted from high energy data into agreement with low energy experiments.

Double-Polarization Experiments at LEGS

The experimental program at LEGS for the next several years is focused on nucleon spin measurements. The only experimental information available on the four spin polarizabilities has come from a LEGS Compton scattering measurement on the proton, and as mentioned above, this yielded a value for γ_p(p) which turned out to be significantly different from theoretical expectations. The *forward spin polarizability* is very difficult to isolate in a Compton measurement. However, there is a QCD sum rule that can be used to evaluate γ_o in terms of an integral, $\int d\omega(\sigma_{3/2} - \sigma_{1/2})/\omega^3$, of π-production cross sections from circularly polarized γ-rays on longitudinally polarized nucleons with beam and target spins parallel and antiparallel, $\sigma_{3/2}$ and $\sigma_{1/2}$, respectively. Here the weighting by a third power in the beam energy (ω) ensures a rapid convergence.

There is considerable interest in the *forward spin-polarizability* sum rule because of its implications for the *Gerasimov-Drell-Hearn* integral, $\int d\omega(\sigma_{3/2} - \sigma_{1/2})/\omega$. The *GDH* sum rule differs only in the energy weighting and can be evaluated in terms of the anomalous magnetic moment of the target, under the reasonable assumption that the Compton spin-flip amplitude vanishes for sufficiently high energies.

The predicted spin-polarizabilities and sum rules of the neutron are considerably different from those of the proton (due to interference terms involving the anomalous magnetic moment). Many higher order theoretical corrections (particularly those involving Δ excitation) are the same for neutron and proton targets, and as a result can be expected to largely cancel in the proton-neutron difference. This difference will provide an important clue to the origin of the discrepancies between theory and experiment. The energy weighting of the sum rule integrals emphasizes low energies and the LEGS experiments will cover 90% and 65% of the γ_o and GDH integrals, respectively.

This program of double polarization measurements at LEGS has required upgrading the capabilities of the facility on several fronts. Obviously, a suitable polarized target needed to be found or developed. Additionally, the energy of the facility was increased in order to provide better coverage for sum rule measurements. Finally, a large solid angle detector array was required in order to acquire data in a reasonable time frame and reduce systematic errors.

SPHICE

The LEGS Spin Collaboration (LSC) has developed a new spin-polarized target ideally suited for this set of experiments. The Strongly Polarized Hydrogen-deuteride ICE target (SPHICE) provides both polarized protons and polarized neutrons in a 'frozen-spin' target. This allows simultaneous investigation of the proton and neutron, thus reducing systematic errors on the critical physics questions with the least theoretical uncertainties.

There are several additional benefits of the SPHICE target:

1. Conventionally dynamically polarized ammonia or butanol targets are diluted with significant quantities of other unpolarized, or even worse partially polarized, background nuclei. Except for 15% aluminum added for improved thermal properties, the HD targets are undiluted.

2. Because backgrounds are small (or nonexistent) it is possible to make absolute cross section measurements. There are essentially no data from direct measurements of absolute cross sections made with conventional polarized targets.

3. The HD targets have true *frozen-spin*. They are not dynamically polarized during the experiment. This fact, together with spin-relaxation times on the order of months, permits the target manufacturing facility to be separated from the experimental hall by any arbitrary distance. These targets are polarized in a dilution refrigerator at very low temperature, 15 milli-Kelvin (mK), and high field, 17 Tesla (T). A special protocol allows the nuclear spins to be frozen and extracted for use at moderate temperatures and low fields in an in-beam cryostat.

The original target development was carried out at Syracuse University. During the past year the collaboration has moved the target production facility to Brookhaven. The dilution refrigerator and associated target production equipment are now installed in the target preparation room adjacent to beamline X5. Highlights of recent and ongoing work include the following:

1. The first unpolarized HD target was placed in the beam in November of 1999.

2. A new mechanism for transferring polarization from H to D has been discovered. This will provide about 8% D polarization in addition to the transfer using traditional RF techniques.

3. The helium liquefier donated by the University of Virginia has been installed and is in the process of being commissioned.

This target is of intense interest to several groups in the nuclear physics community. GRAAL, the European Compton Backscattering facility at the ESRF, is currently creating their own facility for production of these targets. Groups at CEBAF and SPRING-8 are eagerly awaiting our success with the target. At this point the target is the main focus of the local LEGS group's effort at Brookhaven.

SASY

The Spin ASYmmetry (SASY) detector array provides large solid-angle coverage for photoproduction reactions. This allows the simultaneous measurement of several reaction channels over a wide angular range, thus reducing systematic errors and dramatically reducing measurement times.

The array consists of the XTAL Box, an array of 396 NaI detectors that cover an angular range from 45 to 135 degrees around the target, and a forward wall, containing a collection of plastic scintillators and Cherenkov counters. These main components of this calorimeter have been in place and operational for several years now.

The completed array with the inclusion of the TPC (see next section) will be very sensitive to pion photoproduction channels with charged particles in the final state. Because of limited angular coverage for neutron detection, it will not be as sensitive to the neutron-π^0 final state. This reaction will be studied using the neutron barrel, an annular segmented array of plastic scintillator designed to detect neutrons efficiently in the forward region of the XTAL box. The array has been constructed by our collaborators at the University of Rome and is being prepared for installation in SASY.

Time Projection Chamber for SASY

A central *T*ime *P*rojection *C*hamber (TPC) and superconducting solenoid system is under construction to expand the capabilities of the SASY for charged particles (p, π^+, π^-). Magnetic analysis will provide π^+/π^- separation, which is the only practical way to measure reactions on polarized neutrons at the low energies that are important for energy-weighted spin sum rules.

The TPC will also lower the effective thresholds for detection of protons and charged pions.

Collaborators at the University of Virginia have constructed the outer can of the chamber, and the gradient rings, a crucial component that provides a uniform electric field throughout the volume of the TPC, are ready to be installed. At this point the TPC is 50% complete.

The TPC requires a reasonably high, uniform magnetic field over a large volume to allow for the charge separation and momentum analysis of the charged particles. A 1.8T large-bore super-conducting solenoid has been ordered by the collaboration and is scheduled for delivery in summer of 2001.

[1] G. Blanpied, et al. (The LEGS Collaboration), "The $N\rightarrow\Delta$ Transition and Proton Polarizabilities from Measurements of $p(\vec{\gamma},\gamma)$, $p(\vec{\gamma},\pi^0)$, and $p(\vec{\gamma},\pi^+)$," Physical Review C (submitted), BNL Report 67526.